Effect of Post Weld Heat Treatment on the Impact Toughness and Microstructural Property of P-91 Steel Weldment

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Abstract
In the present study it was proposed to find out the optimal welding conditions for the fabrication of alloy steel ASTM A335 Gr. P-91 by the help of Shielded Metal Arc Welding (SMAW). The Shielded Metal Arc Welding (SMAW) process is used to make the entire joint and the root layer is completed by Gas Tungsten Arc Welding (GTAW) process. The pre-heat and inter-pass temperatures were maintained at 200ºC and 250ºC correspondingly in this present work. After welding, the joint was tested for soundness with Radiography testing and after passing the inspection, the Post Weld Heat Treatment (PWHT) was given to the welded joints at 760°C for 3 hrs and 760°C for 6 hrs respectively. The effect of Post Weld Heat Treatment (PWHT) at different holding time was investigated on the Heat Affected Zone (HAZ) of P-91 alloy steel. The Microstructural studies and Radiography and Chapy V-notch impact testing were carried out to investigate the microstructural and mechanical properties of P-91 alloy steel. From the results, it has been observed that as the Post Weld Heat Treatment (PWHT) duration time increases, there is a continual improvement in the impact toughness of the P-91 steel welds.

Keywords
P-91, SMAW, PWHT, HAZ, Impact Toughness

I. Introduction
The efficiency of power generating plants is strongly based on steam temperature and pressure. So due to energy crises, there have been efforts worldwide to increase both: extensive research has been pursued worldwide. The need to reduce fuel costs as well as environmental pollution from fossil fuels by significantly decreasing carbon dioxide emissions from power-generating plants has led to efforts to increase the thermal efficiency of power plants [6, 14].
Material development work over the past two decades has paved the way for large thermal power plants to be built today with live steam temperatures of 610°C, reheat temperatures of 625°C and supercritical steam pressures. The likely potential for reducing the heat rate by increasing the pressure and temperature of the steam admitted to the turbine on the basis of single and double reheating [10]. At live steam conditions of 600°C and 300 bars with double reheating, for example, the heat rate can be reduced by 8% compared with the heat rate of today's standard power stations featuring steam parameters of 540°C/180 bars and single reheat. This improvement in thermal efficiency helps considerably to conserve fuel resources and reduce CO_2 emission by 20%. This objective requires an ambitious development programmed for advanced materials, which can withstand such steam conditions.
This necessitates the use of steels with improved high temperature properties. The development of Cr-Mo ferritic steels, ranging from 1% to 12% Cr-Mo, is of great interest in this regard. The first Cr-Mo ferritic steels was co-developed by the Oak Ridge National Laboratory (ORNL) in USA The continued developments of these steels with the addition and optimisation of Mo, V, Nb and W have resulted in a significant improvement of corrosion and creep resistance properties, enabling the operating temperature to be increased from 565ºC to 650ºC [2]. Among these steels, the modified 9Cr-1Mo-0.2V alloy steel (P-91) is now extensively used all over the world in petro chemical industries, power generating plants and fossil fired boilers [10].
Welding is the important means of fabrication for many of these applications and hence the welding characteristic of P-91 alloy steel constitutes an important criterion for its selection [2, 8]. It has been shown that P-91 steel can be welded satisfactorily by many processes including shielded metal arc welding (SMAW), Gas Tungsten Arc Welding (GTAW) and Submerged arc welding (SAW) process. During the welding of P-91, the pre-heat and inter-pass temperature helps to prevent the possibility of hot cracking due to silicon and niobium content of the weld metal. After welding, the application of Post Weld Heat Treatment (PWHT) is absolutely necessary with grade P91 to reduce the residual stresses that remain locked in a structure as a consequence of manufacturing processes[1, 8, 13].
The objective of this present work is to investigate the effect of Post Weld Heat Treatment (PWHT) at different time conditions, on the microstructural and mechanical properties of grade P-91 steel.

II. Experimental Work
The base metal used in this study was a modified 9Cr-1Mo-0.2V alloy steel plate in the normalized (1080ºC for 1 hr) and tempered (760ºC for 2 hrs) conditions. Its chemical composition as evaluated by optical emission spectroscopy and mechanical properties at room temperature are summarized in Table 1 & 2, respectively.
For welding, the P-91 alloy steel plate was cut into size of 255×260×13 mm by machining process. The dimensions of the weld bead geometry were a root opening of 2.5 mm, a root face of 2.0 mm and inclined single V-groove angle of 60º shown in fig. 2.1.

Table 1: Chemical Composition of P-91 Base Metal, Wt %

Alloying Element	C	Si	Mn	Ni	Cr	Mo	V	S
Wt. %	.1	.3	.4	.2	8.2	.9	.2	.01

Table 2: Mechanical Properties of P-91base Metal at Room Temp

Impact energy (J)	Micro-hardness (HV1)	Yield strength (N/mm²)	Tensile strength (N/mm²)	% El
222	210	534	745	18

The root layer is completed by GTAW process and the entire weld joint was made using SMAW process in three passes. In this investigation E-9018-b9 electrodes were used to make the weld joint. The pre-heat (200ºC) and inter-pass (250ºC) temperatures were maintained in this welding process. After welding, the joint was tested for soundness with Radiography testing and after passing the inspection was given a Post Weld Heat Treatment (PWHT) at 760°C for 3 hrs and 760°C for 6 hrs respectively.

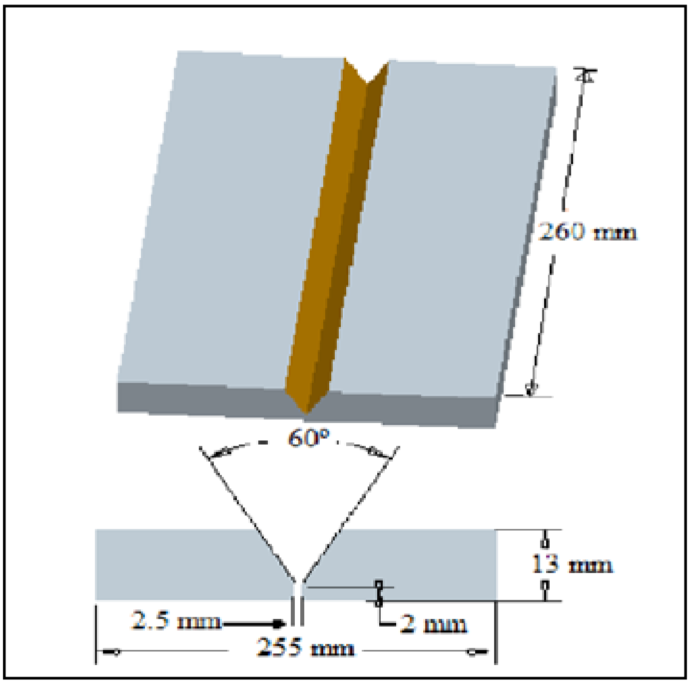


Fig. 1: Weld Bead Geometry

The Charpy impact toughness test was carried out to characterise the ability of different microstructures to absorb energy during the process of fracture. The standard Charpy test specimens of size 55×10×10 mm were cut from the transverse cross section of joints, with the notch located in the HAZ region shown in fig. 2.

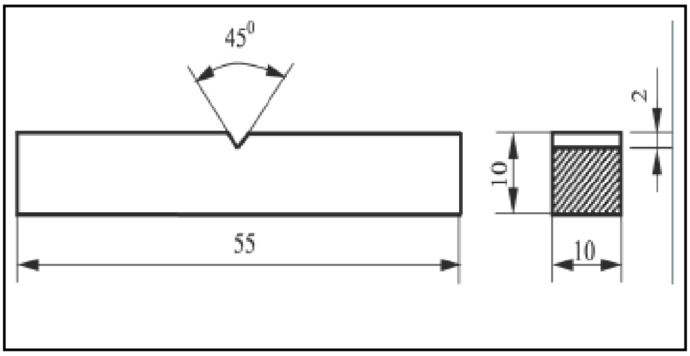


Fig. 2: Standard Charpy Test Specimen

Four specimens were tested at room temperature condition. Light optical microscopy of the HAZ region was carried out using electrolytic etching in a 23% ammonia sol. at 4 V for 45 sec.

III. Results and Discussions

A. Non-Destructive Testing (NDT)

The Non-Destructive Testing (NDT) is carried out to check the soundness of the weld metal, after passing the test, the PWHT was given to the weld specimens.

Fig. 3: Radiography Testing Report

The Table 3 shows the result of Non-destructive testing on the welded joint of the P91 alloy steel. Any types of internal flaws or discontinuities such as cracks, shrinkage, hot tear, insert and molting have not been observed in the weldment.

Table 3: Reference Standard ASTM-446

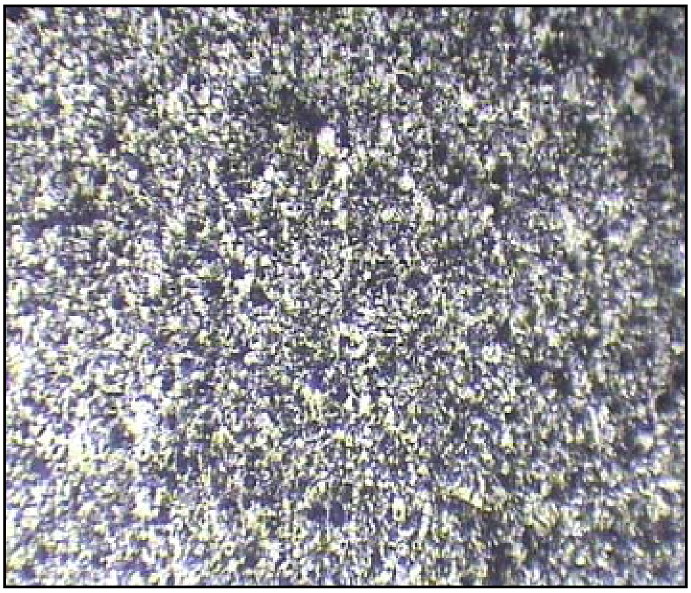
Material	Weld Plate
Surface Condition	Un-Matched
Thickness	13 mm
Focal Size	3 mm
Film Type	ISO Class-C5
Intensifying Screen	Front 0.1 mm, Back 0.2 mm
IQI	ASTM 20 (Plate Type)
Focus to Film distance	50 cm
Technique	SWSI
Density	2.11
Sensitivity	2-2T

Table 4: X-Ray Radiography Test Results

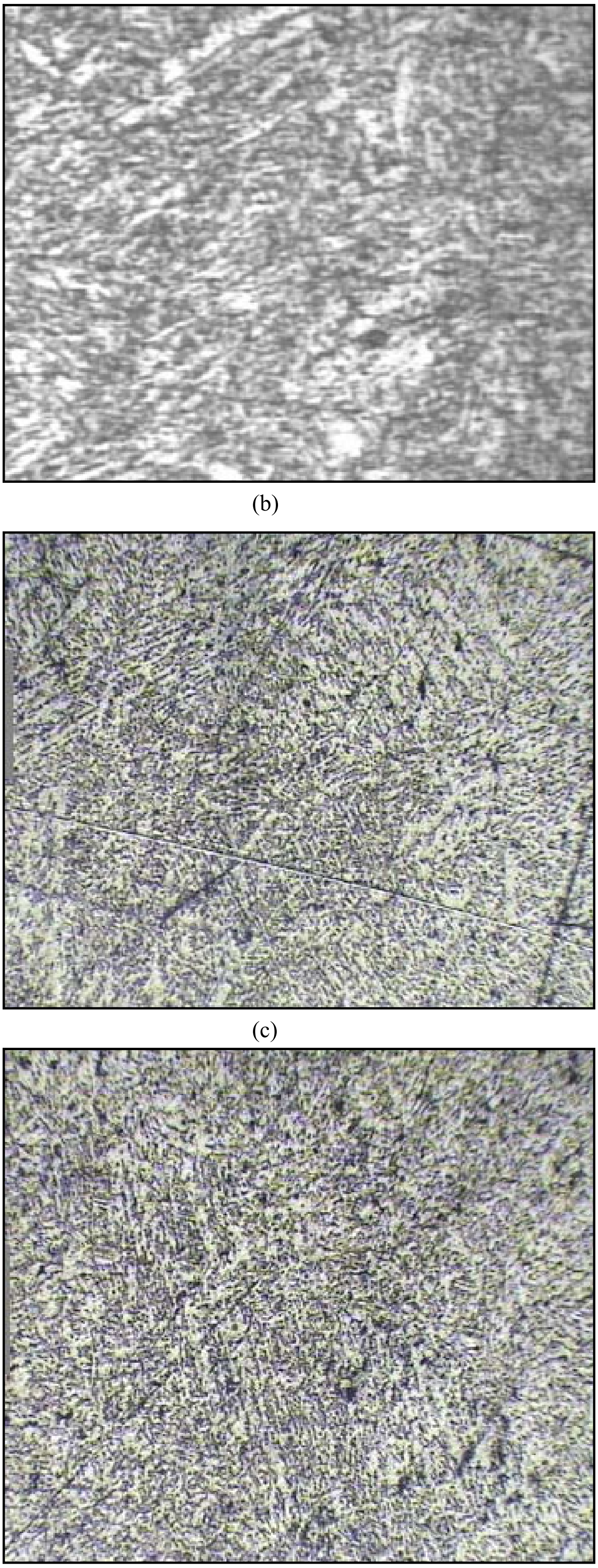
Defects	Gas porosity	Internal shrinkage	Crack	Hot tear	Molting
Levels	Level-2	Nil	Nil	Nil	Nil

B. Microstructures

The optical micrographs at 100X magnification of sources i.e. (a) base metal (b) as welded (c) After PWHT at 760°C for 3 hrs (d) 760°C for 6 hrs are shown in fig. 4.



(a)



(b)

(c)

(d)

Fig. 4: Optical Micrograph, (a) As Received Base Metal (b). As-Welded Condition (c) After PWHT at 760°C for 3 hrs (d) After PWHT at 760°C for 6 hrs

In the as-received condition, the microstructure of the grade P-91 alloy steel base metal (fig. 4(a) consists of fully tempered martensite with small particles on the grain boundaries and some within the grains. The occurrence of patches of ferrite was observed (fig. 4 (b) in as welded condition. After post weld heat treatment PWHT at 760°C for 3 hrs and 760°C for 6 hrs the refinement of grain structure was observed as shown in fig. 4(c) and (d).

C. Impact Toughness

Table 3.3 shows the results of impact toughness of the base metal, as welded and after PWHT at 760°C for 3 hrs and 760°C for 6 hrs. In as welded condition the HAZ region exhibit a poor toughness of 74 J compared to base metal (222 J). But as the PWHT duration time is increases the toughness level of the HAZ region of P-91 weld specimens are increases.

Table 4: Impact Toughness Test Results

Source	Charpy impact test values (J)
Base metal	222 J
As welded	74 J
After PWHT at 760°C for 3 hrs	240 J
After PWHT at 760°C for 6 hrs	258 J

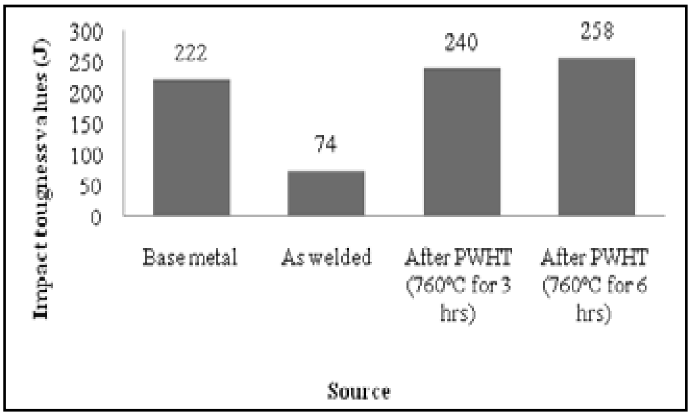


Fig. 5: Impact Toughness

IV. Conclusion

1. As the Post Weld Heat Treatment (PWHT) duration time increases, there is a continual improvement in the impact toughness of the welds.
2. The hardness level and the tensile strength of the P-91 steel's weldment are decreases after increases the Post Weld Heat Treatment (PWHT) holding time from 3hrs to 6hrs.
3. It was found that the acceptable mechanical properties, especially impact toughness, ductility and hardness are obtained only after a Post Weld Treatment (PWHT) at 760ºC for 6 hrs, but for reason of economy, the PWHT at 760ºC for 3 hrs is adequate to get the desired mechanical properties.

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VI. Future Scope

In addition to the present work further work can be done in following directions:

1. The effect of post weld heat treatment (PWHT) at different time conditions, on the Fatigue, Creep and Corrosion resistance properties of the Grade P-91 alloy steel can be studied and the analysis of results can be done by using Design of Experiment's techniques or Finite Element Analysis (FEA).
2. The effect of other variables such as welding consumables, inter-pass & pre-heat temperature on the microstructural properties and the phase transformation occurred in the weldment can be investigated.

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